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COMPUTATION OF EQUITABLE CHARGES FOR TREATMENT OF MUNICIPAL SEWAGE

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PAPERS

COMPUTATION OF EQUITABLE CHARGES FOR TREATMENT OF MUNICIPAL SEWAGE

BY ELLIS E. BANKSON,[1] M. ASCE

SYNOPSIS

Early in 1949, with financial assistance from the City of Pittsburgh, Pa., the State of Pennsylvania, and the federal government, the Allegheny County Sanitary Authority completed preliminary plans for an $82,000,000 collection treatment system for municipal sewage and industrial wastes. The scope and procedure leading to the creation of the Allegheny County Sanitary Authority, and a concise statement of the recommendations of the Authority, have been stated by Jay du Von.[2] A fairly comprehensive statement of the basic financing problems, and their relation to rate making as applied to Allegheny County, has been presented elsewhere by the writer.[3] The present paper, supplementing the former, offers numerical examples of actual computations for the guidance of engineers with similar problems. Items of cost data are numbered consecutively for the convenience of discussers.

INTRODUCTION

The question of equity in a schedule of charges for the collection and treatment of municipal sewage and industrial waste is timely because of the pollution abatement activity throughout the United States, the magnitude of the Pennsylvania program, and the local resort to "revenue bonds" as the adopted basis for all construction funds. By "local" is meant the sphere of influence allotted to the Allegheny County Sanitary Authority, hereinafter called "the Authority." Many water rate schedules just grew, like Topsy, and some sewage rates may follow a similar course, but the following analysis is presented with a view to determining a true equity, in sewage charges, between the various classes of customer types or quantity of service.

NOTE.—Written comments are invited for publication; the last discussion should be submitted by September 1, 1950.

[1] Managing Engr., Allegheny County San. Authority, Pittsburgh, Pa.

[2] "Allegheny County Completes Preliminary Plans for Collection and Treatment System," by Jay du Von, *Water and Sewage Works*, April, 1949, p. 155.

[3] "Allegheny County, Pa., Sets Sewer-Service Charges," by Ellis E. Bankson, *The American City*, January, 1949, p. 88.

It would appear that the outstanding factor of this analysis, aside from the obvious elements of cost allocation, is that of ground-water infiltration into the sewer system of the community, or the relationship between such infiltration and the sewage waste from a particular customer property. It may be noted, however, that the construction and operating costs of the Pittsburgh Metropolitan program include only the intercepter sewers and the sewage works for primary treatment. This is in contrast to a possible complete sewer system and complete sewage treatment, in some other case of particular interest.

In the present case, the construction cost is estimated at somewhat more than $81,000,000 and the annual operating cost is estimated at $1,350,000. Debt service is computed on the basis of a serial, 40-year, revenue bond issue at a 3% interest rate, although the interest rate must, naturally, depend upon market conditions. The resulting interest cost and bond maturity schedule would be covered by a 4.5% rate on the total construction cost, or about $3,650,000 per yr. Inclusion of the aforesaid operating cost would create an annual burden of about $5,000,000, as adopted herein for the basis of cost allocation.

Source of Data for Sewage Flow

The basic data, and the reasoning required for estimating the total revenue bearing sewage to be treated by the Authority in 1954, are as follows:

Item	Description	Gallons per year
1	All sewage from metered water sales in 1945	26,814,597,000
2	All sewage from private water supply in 1945	1,862,696,000
3	By change from flat rate to metered service by 1954	1,447,280,000
4	Increase from domestic customers by 1954	1,534,000,000
5	Increase of commercial and industrial service by 1954	714,225,000
6	A total of metered revenue sewage by 1954	32,372,798,000
7	Estimate of service for 20,000 flat rates in 1954	2,000,000,000
8	A reasonable excess above these conservative figures (for the purpose of a fair analysis on rate structure)	2,127,202,000
9	A fair estimate of total revenue sewage in 1954	36,500,000,000

Item 9 (in gallons per year) can be further classified, in comparison with potential customers in 1954, as follows:

Item	Class	Revenue sewage	Customers
10	Domestic	16,500,000,000	251,251
11	Commercial	11,000,000,000	16,331
12	Industries	9,000,000,000	1,435
13	Total (item 9)	36,500,000,000	269,017

For the purpose of analyzing an equitable rate structure, item 10 includes 2,000,000,000 gal for service to 20,000 domestic customers who may still be on a flat rate basis in 1954, and 2,000,000,000 gal have been added to item 12 as a reasonable anticipated extra service for industry.

The total estimated revenue sewage for 1954 is shown in items 9 and 13. From this beginning, the gross annual output capacity for 1954 is estimated as:

Item	Description	Million gallons
14	The total of revenue sewage for 1954	36,500
15	The average of ground-water infiltration (at 20,000 gal per day per mile of sewer)	16,000
16	Storm water flow and the daily peak of sewage (at about 82% of the ultimate storm water capacity)	20,500
17	Annual output capacity for 1954	73,000

The final computations for estimated unit costs are as follows:

Item	Description		Dollars
18	Estimate of annual burden		5,000,000
	Deduction for Special Revenue and Special Costs:		
19	Annual gain by the "minimum" charge	40,000	
	Estimate of Surcharge for Extra Concentration of sewage—		
20	(*a*) Conservative estimate	60,000	
21	(*b*) Possible extra load	50,000	
22	Total surcharge (items 20 and 21)	110,000	
23	Allocation of annual cost for normal quality of sewage: 800,000 (item 60) minus 110,000 (item 22)	690,000	
24	Total deductions (items 19 to 23)		840,000
25	Allocation of annual cost for the treatment of sewage on the quantity basis (item 18 minus item 24)		4,160,000

Dividing $4,160,000 (item 25) by 73,000,000,000 (item 17), the unit cost is found to be 5.7¢ per thousand gal.

Unit Cost of Sewerage Service for an Average Household

The average quantity of domestic sewage in Allegheny County is indicated at about $\frac{16{,}500{,}000{,}000 \text{ gal (item 10)}}{1{,}500{,}000 \text{ population}}$, or 11,000 gal per yr per person. This would mean an average of 30 gal per day for each person, or 120 gal per day for a family of four. Admittedly, there is a wide range above and below this average value. To this figure should be added the ground-water flow and extra provision for storm water.

The total length of all sewers within the service area is about 2,200 miles, or 11,616,000 ft, for a sewerage service to some 269,017 customers (item 13), or about 43 ft of sewer for each average customer. These totals include all the commercial and industrial customers that may require a much greater sewer frontage than the average. If all costs are to be covered by current bills to active customers (as is probably required for a revenue bond issue), the total length should include vacant lots. On this basis, the average of sewer length for an average residence would be something less than 43 ft each.

An estimated population of 1,500,000 in 1954 would require $\frac{11{,}616{,}000}{1{,}500{,}000}$, or about 7.7 ft per person, which is 30.8 ft for a house of four persons, as an average. The average length per person in single residences, however, would doubtless exceed 8 ft; and the average per person living in large apartment buildings would be much less. Since the average household of the county

contains a scant four persons each, the average length would be 4 × 8 = 32 ft of sewer for each average residence, by this method.

In this case, an infiltration of about 20,000 gal per day per mile of sewer (item 15), for rate making purposes, would mean about 3.8 gal per day per ft of sewer, or nearly 115 gal per day of infiltration for a household of four at 30 ft of sewer per house. The cost of storm water capacity should be allocated in an amount that is at least equal to that of ground-water infiltration, or more, because the 73,000,000,000 gal in item 17 is based on a storm water flow that is higher than the average of ground-water infiltration. The cost for storm water, therefore, would equal at least that for infiltration, or the equivalent cost of 115 gal per day per average house.

The average capacity in gallons required to service the normal household of four persons will be as follows:

Item	Description	Quantity
26	Infiltration	115
27	Domestic sewage	120
28	Storm water capacity	115
29	Total per sample household of four	350

—and the resulting quantity cost of the sewerage service is 350 gal (item 29) at 5.7¢ per thousand gal, or 2¢ per day for 0.12 thousand gal (see item 27). The cost per gallon of domestic sewage capacity is 2/0.12 = 16.6¢ per thousand gal.

The cost allocation for normal sewage quality is estimated at $690,000 per yr (item 23) for the 36,500,000,000 gal of customer sewage (item 9), or less than 1.9¢ per thousand gal of sewage from the customer property. The sum of the two units (16.6 plus 1.9) indicates a total of 18.5¢ per thousand of domestic sewage from customer property.

Division Between Quantity and Quality Costs

The entire cost of the sewage collection system is properly allocated to the "quantity" of sewage. In addition, certain features of the plant cost are attributable to "quantity" and would be substantially the same regardless of the sewage strength. Other features are a direct result of the quality of sewage —that is, the biochemical oxygen demand (B.O.D.) and the suspended solids content. An analysis of the capital expenditure for the various components of the central treatment plant is presented in order that the annual debt service for the plant may be distributed between quantity and quality of the sewage, as follows:

Distribution As to Quantity—

Item	Description	Cost, in dollars
30	Pump station	2,800,000
31	Sewage meter	50,000
32	Grit chambers and comminutors	670,000
33	Sedimentation tanks	2,610,000
34	Power and boilers	1,800,000
35	Plant conduits and outlets	545,000
36	Administration building, garage, exterior piping, and miscellaneous	906,000
37	Total (55% of item 47)	9,381,000

Distribution As to Quality—

Item	Description	Cost, in dollars
38	Pre-aeration tanks	520,000
39	Blower plant	436,000
40	Sludge digestion plant	3,619,000
41	Elutriation tanks	145,000
42	Mechanical dewatering plant	946,000
43	Sludge drying and incineration	1,553,000
44	Gas utilities	150,000
45	Chlorination plant	250,000
46	Total (45% of item 47)	7,619,000
47	Grand total, based on a plant designed for 180,000,000 gal per day (items 37 and 46)	17,000,000

Items 37 and 46 indicate that 55% of debt service is allocated to quantity cost and 45% to quality cost. However, the annual operating expenses of the treatment plant, as distinguished from the initial capital expenditures, are estimated as 45% chargeable to quantity cost and 55% chargeable to quality.

Summary of Quantity and Quality Costs

The cost allocation between collecting system and treatment plant is computed as follows: The initial construction cost of the collecting system is $64,477,000, or about 80% of the direct construction cost of $81,052,000, for the entire project. Therefore, the annual debt service cost arising from the collecting system is 80% of $3,650,000, or $2,920,000. In a similar manner, about $500,000 of the $1,350,000 for annual operating and maintenance cost (about 37%) is properly allocated to the collecting system. The remainder in each case would be properly allocated to the sewage treatment plant at $730,000 for debt service and $850,000 for operation cost as follows:

Annual Cost Attributable to Collecting System—

Item	Description	Dollars
48	Debt service (80% × $3,650,000)	2,920,000
49	Operating cost (37% × $1,350,000)	500,000
50	Total	3,420,000

Annual Cost Attributable to Treatment Plant—

Item	Description	Dollars
51	Debt service (20% × $3,650,000)	730,000
52	Operating cost (63% × $1,350,000)	850,000
53	Total	1,580,000

The former charge of $3,420,000 (item 50) is properly allocated completely as a quantity cost in contrast to the latter item of $1,580,000 (item 53) which is allocated as partly a quantity cost and partly a quality cost. The division of this sewage treatment cost is indicated by items 37 and 46, respectively, as 55% of the debt service and 45% of the operating expenses to quantity cost and the remainder of 45% debt service and 55% operating expenses to quality cost.

A summary statement of the division between quantity cost and quality cost may now be made as follows:

Annual Costs Chargeable to Quantity of Sewage—

Item	Description	Dollars	
54	Annual costs of collecting system	3,420,000	
55	55% of annual treatment plant debt service (55% × $730,000) (item 51)	401,500	
56	45% of annual treatment plant operating expenses (45% × $850,000) (item 52)	382,500	
57	Subtotal (84% of item 61)		4,204,000

Annual Costs Chargeable to Quality of Sewage—

Item	Description	Dollars	
58	45% of annual treatment plant debt service (45% × $730,000)	328,500	
59	55% of annual treatment plant operating expenses (55% × $850,000)	467,500	
60	Subtotal (16% of item 61)		796,000
61	Total annual costs		5,000,000

It may be argued that the debt service from the sludge digestion plant should be counted as a quantity cost, because it develops power that is used for the pumping of sewage quantity. At the same time it may be argued that the allocation of operating cost is too heavy on the quantity side. A change of both would leave the final answer approximately the same as indicated by items 54 to 61.

Unit Cost of Sewerage Service for a Large Office Building

Detailed data for the nine office buildings included in the study are as follows:

Item	Name of office or building	Feet of sewer in street	Gallons per year
62	Law and Finance Building	220	5,478,000
63	Grant Building	500	16,454,000
64	Gulf Building	600	22,379,000
65	Koppers Building	560	20,220,000
66	Oliver Building	570	74,122,000
67	Park Building	300	22,287,000
68	Pittsburgher Hotel	210	21,842,000
69	Union Trust Building	1,160	24,162,000
70	William Penn Hotel	1,100	119,529,000
71	Totals	5,220	326,473,000

If the ground-water infiltration is allocated equally to both sides of the street, at the rate of 3.8 gal per day per ft of sewer, the total allocation against these nine office buildings is at the rate of 9,918 gal per day or about 3,620,000 gal per yr, as 1.1% of the water sales.

The addition of this quantity for infiltration and a similar quantity for storm water capacity would produce a total flow per year from these nine office buildings of about 333,740,000 gal, which, at 5.7¢ per thousand gal, represents a cost of $19,023.18. Unit costs, in dollars per thousand gallons, are as follows:

Item	Description	Quantity
72	Quantity cost: $\frac{19,023.18}{326,500,000}$	5.8
73	Quality cost	1.9
74	Total (items 72 and 73)	7.7

A fair comparison can be made between the 18.5¢ per thousand gal, as the top rate for domestic service, and the 7.7¢ per thousand gal as an equitable rate for a large office building, or an equivalent industry.

Basis of Cost Data

The extension of the foregoing analysis to the component parts of the whole, by reduction ratios, is treated in this section. As basic data, consider the following sources of sewage quantities (in schedule units of thousand gallons per day) for the year 2000:

Item	Description	Quantity
75	Average sewage from customer properties	165,039
76	The peak of sewage flow from customer properties	226,118
77	Ground-water infiltration	80,775
78	Provision for storm water flow	66,688
79	Computed peak rate of plant inflow	375,581

In item 77 the ground-water infiltration is computed at the rate of 25,000 gal per day per mile of sewer; and, in item 78, the storm water flow is presented as the difference between the dry weather peak flow and the peak of flow during storm. The corresponding allocation as to class of customer is as follows:

Item	Group items	Domestic	Commerical	Industrial	Total
80	Customer sewage	78,661	46,274	40,104	165,039
81	Infiltration	64,620	12,116	4,039	80,775
82	Subtotals	143,281	58,390	44,143	245,814
83	Storm water	56,324	10,990	1,374	68,688
84	Total allocation	199,605	69,380	45,517	314,502
85	Reserve capacity for daily peak flow at the foregoing composite ratio for all classes				61,079
86	Computed peak rate of plant inflow (items 84 and 85)				375,581

In item 81 the infiltration is reported at a certain ratio for each class, determined by observation, experience, and judgment regarding the length of

sewer. Item 83 (storm water) also is determined on a judgment basis. The ratio for industry, in this case, is further decreased because industries are located along a river and therefore most of the storm water can drain directly to it over the ground surface. Item 86 was computed[4] as 579.6 cu ft per sec of maximum inflow at the sewage plant, for the year 2000.

A weighted average cost allocation is evolved by a comparison of quantity ratios and quality ratios, as follows:

Item	Group items	Domestic	Commercial	Industrial	Total
87	Quantity ratio (from item 84)...	64%	22%	14%	100%
88	Quality ratio[5].....	43%	26%	31%	100%
89	Weighted average cost allocation.	61%	23%	16%	100%

The quality ratio in item 88 has been established by dividing the cost estimates between the quality and quantity function. For instance, the function of the digesters is related to concentration or quality and the function of the interceptors is related only to the quantity of sewage flow.

Division of Annual Burden Between Customer Classes

The annual burden is divided between customer classes as follows:

Item	Group	Domestic	Commercial	Industrial	Total
90	Annual burden, 1954, at the cost ratio (item 18).....	$3,032,000	$1,132,000	$836,000	$5,000,000
	Gain in Special Revenue Items of Direct Allocation				
91	"Minimum charges"	40,000	....	....	40,000
92	Allocated base by surcharge estimate....	....	....	60,000	60,000
93	Possible extra by surcharge estimate....	....	....	50,000	50,000
94	Remainder of 1954 annual burden for revenue sewage....	$2,992,000	$1,132,000	$726,000	$4,850,000
95	Revenue sewage, 1954, in units of thousand gallons (items 10 to 13).....	16,500,000	11,000,000	9,000,000	36,500,000

Dividing item 94 by item 95, the average unit costs by customer classes for the year 1954 are:

Item	Unit	Domestic	Commercial	Industrial	Total
96	Cents per thousand gallons....	18+	10+	8+	13+

The adopted schedule of sewerage charges will allow for a range of rates (in cents per thousand gallons of sewage) from 18¢ at the top to 7¢ at the bottom, as compared to the average cost for each group of service as given in item 96.

[4] "Preliminary Report," Allegheny County San. Authority, Pittsburgh, Pa., 1949, Appendix VII, Pt. 9, p. 168.

[5] *Ibid.*, Appendix XXI, p. 67.

Industrial Wastes

The regular schedule of sewerage charges would apply for the quantity of industrial wastes except that a surcharge would also apply for concentrations that are higher than the average.

Let: F equal a factor to be applied to the basic rate; $R = 0.15$ be a ratio of quality cost to total annual cost; S be the suspended solids in sewage, in parts per million—S_i denoting a particular industry and $S_a = 275$ denoting the average for all sewage; and B equal the B.O.D. of sewage—B_i and $B_a = 300$, respectively, being that of a particular industry and the average of all sewage. Then:

$$F = 1 + R\left[\frac{0.75\,(S_i - S_a)}{S_a} + \frac{0.25\,(B_i - B_a)}{B_a}\right] \quad \ldots\ldots\ldots\ldots (1)$$

Eq. 1 contains an arbitrary division between the solids content and the organic matter. An alternate formula has therefore been considered, without the arbitrary feature, as follows:

$$P = Q\,C\,X\,(S_i - S_a) + Q\,C\,Y\,(B_i - B_a) \quad \ldots\ldots\ldots\ldots (2)$$

in which P is the surcharge, in dollars, for the billing period; Q is the quantity of sewage, in million gallons, for the billing period; $C = 8.34$ is a constant for converting parts per million to pounds per million gallons; X equals about one third of a cent is the cost of treating one pound of suspended solids; and Y equals about one tenth of a cent is the cost of treating one pound of B.O.D.

Comparing Eqs. 1 and 2, it may be noted that the resulting surcharge for one famous industry would be $4,791 per yr by the first formula and $5,126 by the second. For another famous industry, the surcharge would be $14,321 per yr by the first formula and $12,831 by the second.

Summary

Through item 74 the analysis is illustrated by an example of an average household, for collection and treatment costs of domestic sewage, and by an example of nine office buildings for the quantity cost of high demand within a small area. In contrast, items 75 to 96 represent a composite analysis for unit costs on design quantities, without illustration by example or type. It will then be noted that the two methods produce similar results.

For domestic use of about 30 gal per capita, the infiltration will roughly equal the water sales. A further inclusion of storm flow capacity, at a cost about equal to the water sales, will require an interceptor capacity, for domestic sewage (on customer premises), of about three times the domestic water sales as compared to slightly more than 2% for the case of very large office or hotel buildings.

As limited to interceptor sewer collection and primary sewage treatment, the slide in this particular rate schedule of sewage service charges is found to range from 18¢ per thousand gal at the top to an average of 7.7¢ per thousand gal at the bottom (or 8¢ + by the composite study). This unit (7.7¢ per thousand gal) is the average cost for concentrated high water use. The low block rate,

or charge, will be lower than 7.7¢ because of the higher rates or charges on the first blocks or steps of quantity service. Inclusion of lateral and trunk sewers, or secondary treatment and other differences, would affect the ratio between this extreme spread of service cost.

The total of those costs that relate to the quality of normal sewage flow is 1.9¢ per thousand gal and that relating to quantity of sewage at the treatment plant is 5.7¢ per thousand gal, or approximately a total of 17¢ per thousand gal on domestic water sales.

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